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Review

The composition, extraction, functionality and applications of rice proteins: A review

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ABSTRACT

Background: Rice is a staple food and an important source of proteins in many regions worldwide. Its protein component is generally regarded as hypoallergenic, and a number of studies have highlighted the nutritional and health benefits associated with consumption of rice proteins. In recent years, the processing of plant proteins has drawn scientific and industrial interest, and rice protein-enriched ingredients have become commercially available.

Scope and Approach: The aim of this study was to provide a critical review of the state of the art regarding the composition, extraction methods, functional properties and applications of rice proteins.

Key Findings and Conclusions: Rice is composed of four protein fractions, namely albumin (water-soluble), globulin (salt-soluble), glutelin (alkali-soluble), which represents the dominant protein in brown and milled rice, and prolamin (alcohol-soluble), a minor protein in all rice milling fractions. Different methods to extract proteins from rice, including alkaline, enzymatic and physical methods, have been, and continue to be, evaluated for their efficacy, and some have been applied industrially. However, only a limited amount of studies have described the functional properties of rice proteins and how these can be improved by means of enzymatic hydrolysis. Applications of intact rice proteins are limited due to their poor solubility in water. However, hydrolysed rice proteins are used in the formulation of hypoallergenic infant formulas and may potentially be used in a variety of food systems due to their improved functionality. Despite the advances in the characterisation of rice proteins, a greater understanding of their physicochemical properties and how to modify their functionality is required in order to expand their range of food applications.

1. Introduction

Rice (*Oryza sativa* L.) represents one of the leading food crops in the world, with a global annual production estimated at about 480 million metric tons (milled rice basis) (USDA, 2015), and it is cultivated today in more than 100 countries, on every continent except Antarctica. It is the staple food for over half the world's population, mainly in Asian countries, where it provides a considerable proportion of the protein intake for millions of people (Muthayya, Sugimoto, Montgomery, & Maberly, 2014). Its total food protein production per hectare is second only to that of wheat, although the yield of utilisable protein is actually higher for rice than for wheat, due to the superior quality of rice proteins (Childs, 2004). Proteins significantly influence structural, functional and nutritional properties of rice, and their characterisation has been the subject of extensive research (see previous reviews by Fabian & Ju, 2011; Hamaker, 1994; Juliano, 1985; Lasztity, 1995; Shih, 2003, 2004). The protein digestibility and biological value of rice have been reported to be higher than those of the other major cereals (i.e., wheat, corn and barley) (Eggum, 1979). Also, rice proteins are generally regarded as hypoallergenic (Helm & Burks, 1996), with several studies suggesting that rice proteins (in many cases, rice protein-based hydrolysates and specific peptide fractions therefrom) have anti-oxidative (Adebiyi, Adebiyi, Yamashita, Ogawa, & Muramoto, 2009b; Burris et al., 2010; Chanput, Theerakulkait, & Nakai, 2009; Yang et al., 2012b; Zhang et al., 2010, 2009; Zhao et al., 2012b), anti-hypertensive (Li, Qu, Wan, & You, 2007), anti-cancer (Kannan, Hettiarachchy, Johnson, & Nannapaneni, 2008; Kannan, Hettiarachchy, & Narayan, 2009; Kannan, Hettiarachchy, Lay, & Liyanage, 2010) and anti-obesity (Yang et al., 2011, 2012a,

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2007; Kannan, Hettiarachchy, & Mahedevan, 2012; Zhang, Bartley, Mitchell, Zhang, & Yokoyama, 2011) activities. Therefore, rice represents an interesting source of proteins for the development of protein-enriched ingredients for the formulation and manufacture of nutritional products.

2. Distribution and composition of proteins in rice

The protein content of rice is usually calculated from Kjeldahl nitrogen multiplied by the nitrogen-to-protein conversion factor of 5.95, which is based on the nitrogen content (16.8%) of glutelin, the major rice protein, although a nitrogen-to-protein conversion factor of 6.25 is used in nutritional studies in order to maintain a common nitrogen-based calculation for all proteins (Shih, 2004). Rice grain milling fractions differ in terms of protein content, with that of brown rice, i.e., the rice caryopsis, being higher compared to milled or white rice (composed entirely of endosperm) due to the removal of the protein-rich bran during milling (Table 1). Rice bran consists of a fine, floury material, which includes pericarp, seed coat, nucellus, aleurone, pulverized embryo, and some hull and endosperm fragments (Orthoefer & Eastman, 2004) (Fig. 1). The protein content of rice is influenced by factors such as management and cultural practices, climate and genotype (Champagne, Wood, Juliano, & Bechtel, 2004).

2.1. Rice protein fractions

Rice proteins are categorized according to the solubility-based classification described by Osborne (1924); albumin (water-soluble), globulin (salt-soluble), glutelin (alkali/acid-soluble), and prolamin (alcohol-soluble) are the four main rice protein fractions.

Rice proteins are mainly observed in the form of storage organelles called protein bodies (PBs). Two types of morphologically distinct PBs have been identified in rice endosperm, namely type I (PB-I) and type II (PB-II) (Fig. 2). PB-I has a lamellar structure, is spherical in shape and is rich in prolamin, whereas PB-II has a crystalline structure, displays an irregular shape and contains predominantly glutelin (Bechtel & Juliano, 1980; Bechtel & Pomeranz, 1978; Ogawa et al., 1989, 1987; Tanaka, Sugimoto, Ogawa, & Kasai, 1980). According to Ogawa et al. (1987), endosperm storage proteins comprise 60–65% PB-II, 20–25% PB-I and 10–15% albumin and globulin in the cytoplasm.

Rice grain milling fractions differ in terms of protein composition (Table 2). Data reported in the literature regarding rice protein solubility fractions vary widely, depending on the rice variety and the extraction procedures. Albumin, globulin, glutelin and prolamin have been reported to account for 5–10, 7–17, 75–81 and 3–6%, respectively, of total protein in brown rice, 4–6, 6–13, 79–83 and 2–7%, respectively, of total protein in milled rice, and 24–43, 13–36, 22–45 and 1–5%, respectively, of total protein in rice bran (Adebiyi, Adebiyi, Hasegawa, Ogawa, & Muramoto, 2009a; Agboola, Ng, & Mills, 2005; Cao, Wen, Li, & Gu, 2009; Ju, Hettiarachchy, & Rath, 2001; Juliano, 1985; Zhao et al., 2012a). Glutelin is the main protein fraction in brown and milled rice, whereas prolamin, which represents the major endosperm storage protein in all other cereals except oats (Shewry & Halford, 2002), is a minor protein in all rice grain milling fractions.

Table 1
Chemical composition (%) of rice grain milling fractions at 14% moisture (adapted from Juliano & Bechtel, 1985).

	Brown	Milled	Bran
Protein (N × 5.95)	7.1–8.3	6.3–7.1	11–15
Crude fat	1.6–2.8	0.3–0.5	15–20
Available carbohydrates	73–76	77–78	34–52
Starch	66	78	14
Crude fiber	0.6–1.0	0.2–0.5	7.0–11
Crude ash	1.0–1.5	0.3–0.8	6.6–9.9

Differences in protein composition of the rice milling fractions result in differences in the nutritional quality of their protein component. Han, Chee, and Cho (2015) showed that rice bran protein has a higher nutritional quality than rice endosperm protein; protein efficiency ratio (PER), net protein retention (NPR) and net protein utilisation (NPU) were 2.39, 3.77 and 70.7, respectively, for rice bran protein, and 1.96, 3.26 and 61.4, respectively, for rice endosperm protein. PER and NPR were higher for both rice protein ingredients compared to soy protein isolate (SPI) (1.71 and 3.04, respectively, for SPI), but lower compared to casein (2.58 and 4.02, respectively, for casein) and whey protein isolate (WPI) (3.26 and 4.54, respectively, for WPI). Of those protein ingredients analysed by Han et al. (2015), WPI was the only ingredient with a higher NPU (74.0) than rice bran protein. Also, rice bran protein had true digestibility (TD), biological value (BV) and protein digestibility-corrected amino acid score (PDCAAS) of 94.8%, 72.6% and 0.90, respectively, whereas the same indices for rice endosperm protein were 90.8%, 66.7% and 0.63, respectively. PDCAAS of rice endosperm protein, but not that of rice bran protein, was considerably lower compared to that of the other ingredients analysed, which had values ranging from 0.95 (SPI) to 1.00 (casein and WPI). However, for both rice protein ingredients, TD was comparable to that of SPI (91.7%) and dairy protein ingredients (92.8–94.8%), whereas BV was lower than only that of WPI (78.8%). Furthermore, rice endosperm and rice bran proteins had a similar content of total essential amino acids (41.1–41.7 g/100 g protein) to that of SPI (41.2 g/100 g protein), but these values were significantly lower compared to those observed for casein and WPI (50.6–55.2 g/100 g protein) (Table 3).

An analysis of the amino acid profile of individual rice proteins (Table 4) shows that prolamin has the lowest content of lysine, the first limiting amino acid among cereal proteins (Young & Pellett, 1994). The highest lysine content is found in albumin, followed by glutelin and globulin. Being rich in albumin, rice bran displays a higher content of lysine compared to brown or milled rice. Also, due to the low content of prolamin, rice has a higher lysine content than other cereal grains (Day, 2013). As regards the other essential amino acids, albumin shows the highest content of histidine and threonine, whereas prolamin has the highest proportions of isoleucine, leucine and phenylalanine. Furthermore, globulin has the highest content of the sulfur-containing amino acids cysteine and methionine, while prolamin has the lowest. Based on their amino acid composition, albumin has been estimated to have the highest and prolamin the lowest BV among the rice protein fractions (Padhye & Salunkhe, 1979).

2.1.1. Albumin

Albumin is readily soluble in water due to the presence of sufficient net charge and the lack of any extensive disulfide cross-linking or aggregation (Hamada, 1997). However, globulin contamination occurs when albumin is extracted with water, because of minerals present in the rice grain that dissolve in water, thus increasing the solubility of globulin (Villareal & Juliano, 1981). Therefore, in order to obtain purified albumin at laboratory scale, additional steps have to be carried out, which include repeated precipitation, centrifugation and dialysis (Hamada, 1997; Iwasaki, Shibuya, Suzuki, & Chikubu, 1982; Mawal, Mawal, & Ranjekar, 1987). Application of isoelectric focusing (IEF) (pH 3.5–10) to milled rice albumin revealed 16–18 bands, 10–11 of which had isoelectric point (pI) in the range 6.0–7.5 (Villareal & Juliano, 1981). However, only one band, with pI 6.4, was found in the study of